

distribution may be general. It should be noted, however, that 6 h. 30 m. to 9 h. is the only period of the day showing an entire absence of negative rotations, while 12 hours later we find the greatest incidence of these, along with an entire absence of positive rotations.

*On the Direction of Motion of an Electron ejected from an Atom
by Ultra-Violet Light.*

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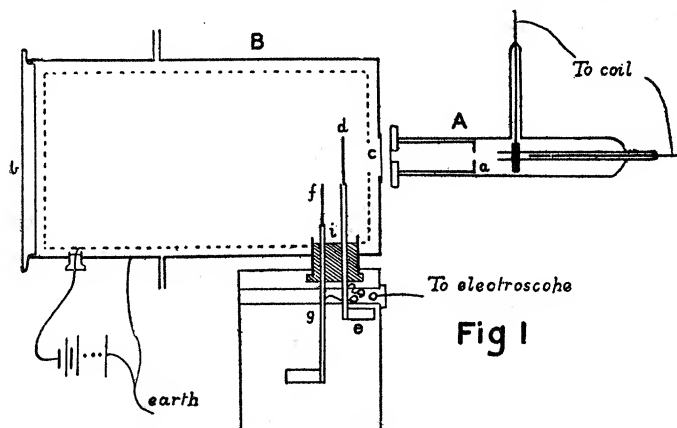
(Communicated by Prof. Sir J. J. Thomson, F.R.S. Received March 25,—
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When light is absorbed by matter it exerts, according to the electromagnetic theory of light, a pressure upon the matter, or gives a momentum to it, in the direction of propagation of the light. The existence of this pressure has been proved by a number of observers. When ultra-violet light is absorbed by matter we know that a part at least of the absorbed energy is expended in liberating cathode rays of small velocity. The momentum corresponding to the absorption of energy in this case thus probably appears in part in the form of moving electrons. We would, therefore, expect these cathode rays to have a component of velocity in the direction of propagation of the light.

The results that have been obtained in experiments on the secondary cathode radiation from substances exposed to γ - and X-rays also suggest that possibly such an effect exists. Thus the larger amount of secondary β radiation given off from the side of a radiating plate where the stream of exciting γ -rays emerges than where it enters has been explained by Prof. Bragg by supposing that the secondary β -rays are projected in the direction of propagation of the γ -rays. Cooksey showed that a similar effect exists with X-rays. It appeared a promising experiment therefore to look for such an effect in the case of ultra-violet light, and the writer accordingly carried out a set of measurements to test this point.

The apparatus by means of which the experiment was carried out is shown in fig. 1. The source of ultra-violet light was a vacuum tube A in which the discharge took place between an aluminium ring and an aluminium rod contained in a glass tube. It contained hydrogen at a pressure of a few millimetres. The electrodes were connected with the secondary circuit of an

induction coil whose primary circuit was connected with the 100 volts alternating electric light leads. Three Leyden jars were placed in the secondary circuit to increase the brightness of the discharge. A pencil of



light was obtained by means of the stop *a*, the light leaving the tube by a circular thin quartz window 3 mm. in diameter at one end of the stop. The intensity of the pencil of light obtained was very constant.

B is a cylindrical brass chamber 8 cm. long and 7.5 cm. in diameter; it was closed at one end by a brass lid *b*, and the other end by a brass plate which had a circular quartz window *c*, 2 cm. in diameter, at the centre. Inside this chamber was another of the same shape but of wire gauze, the distance from the wire gauze to the inside surface of the brass chamber being about 0.5 cm. The inside wall of the chamber and the gauze were covered with lamp-black to increase their absorption of stray light and thus to reduce the amount of light reflected across the chamber. The chamber was earthed and the gauze usually connected to a high positive potential. The arrangement acted as a trap for the ions made near the surface of the chamber wall and the wire gauze by stray ultra-violet light; it is a better method than not using a gauze and having the chamber at a high positive potential to draw the cathode rays produced back into the metal.

A circular quartz plate *d*, about 0.3 mm. thick and 2.5 cm. in diameter, was mounted on a brass rod which passed through a brass tube mounted in an ebonite stopper *i*, so that the plate could be brought into the path of the beam of light or removed out of it as desired. The rod could also be rotated round its axis by means of the vane *e*. The quartz plate was covered on one side with a very thin film of platinum deposited on it from a platinum cathode in a discharge tube. Films of uniform thickness and of any desirable thinness can be obtained in this way.

The cathode radiation of the film under the action of ultra-violet light was investigated. An electric field was applied between the gauze and film in such a direction that the cathode radiation was pulled away from the film, the positive charge left behind being measured. It was of importance that the film should be very thin, so that the amount of cathode radiation corresponding to the amount of light absorbed might be as large as possible. The quartz plate did not show any appreciable change in appearance after the process of depositing the film till held over white paper, when it appeared just slightly darkened. The electrical conductivity of the film was tested and it was found that an electroscope could be charged practically instantaneously to any desired potential through the film. The surface of the other side of the plate was tested in the same way and found to insulate perfectly.

An aluminium plate *f*, covered on one side with two layers of gold leaf, was mounted on a rod *g* in the same way as the quartz plate. The rod slid freely in a brass tube mounted in the ebonite stopper *i*.

When the quartz plate was in the path of the beam of light and the rod *e* connected with the electroscope a large leak of positive electricity—about 10 divisions in 15 seconds—was obtained when the gauze was at a positive potential of 200 volts. But when the potential was reversed the leak was stopped. This shows that the platinum film emitted practically only negative particles under the action of the ultra-violet light, while the corresponding positive charge remained on the film; in the former case these negative particles were pulled away from the film, leaving it positively charged, and in the latter case they were driven back into the film. A very small fraction only of the leak was caused by the light reflected from the chamber walls. This was tested by measuring the leak with the quartz plate not in the beam of ultra-violet light, the leak being now solely caused by light reflected by the chamber walls and the gauze. The leak was found to have decreased to about 5 per cent. of the previous value.

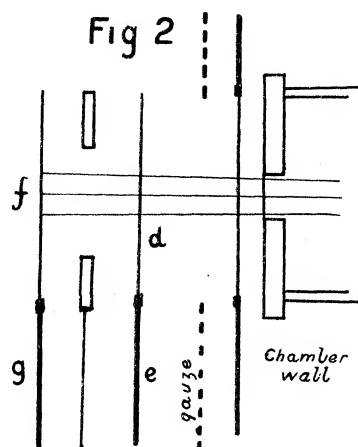
A set of measurements was then carried out with the platinum film on the quartz plate facing the source of ultra-violet light, and with the film facing in the opposite direction, the plane of the plate being at right angles to the beam of light in each case. The plate *f*, by means of which the absorption of the light by the plate *d* was measured later, was moved out of the path of the beam of light and kept earthed. The potential of the gauze was always positive, usually from 200 to 600 volts. It was found that when the platinum film was facing away from the source of light the leak was about 15 per cent. larger than when the film was facing the light. Thus, for example, when the gauze was at a potential of 600 volts the leak in the former case was 20 divisions in 27·9 seconds, and in the latter case 20 divisions in 32·8 seconds.

Now, when the film is facing away from the source of light, the intensity of the light emerging from the film is less than the intensity of the light falling on to the film when it is facing the other way. Therefore, if the electrons are ejected in all directions and the amount of light reflected by the film is the same in the two cases, a smaller leak should be obtained in the former case than in the latter. The opposite result could only be obtained if the ejected electrons have a component of velocity in the direction of propagation of the light.

The experiments were carried out with the air in the chamber at atmospheric pressure, and an intense field was therefore necessary to pull the electrons away from the film on account of their small penetrating power. The effect could not have been due to a lack of saturation of current, for the form of the apparatus was such that the field operating when the film was facing the source of light was more powerful than in the other case, as is shown in the figure, which would produce an effect contrary to the one observed. However, to make sure about this point measurements were carried out with fields of different strengths, and in one set of measurements the chamber was full of hydrogen, which would enable the ejected electrons to get further away from the plate than in the case of air. But the degree of the asymmetry of the leaks was not materially changed in any case.

It was also necessary to test whether the asymmetry in the leaks was due to a change in capacity occurring when the vane *e* was rotated through an angle of 180° . The apparatus was built so that the capacity should remain practically the same. Whether this was realised or not was tested by replacing the quartz plate by the plate *f*, and measuring the leaks produced by the γ -rays of a small quantity of radium placed near the chamber for the two positions of the vane. The mean leaks obtained were 53.5 and 53.7 seconds for 15 divisions of scale, which show that there was no appreciable alteration in capacity with the change of position of vane.

Some experiments were next made to see whether the reflection of light by the quartz plate and platinum film had anything to do with the asymmetry of leaks observed. A circular plate, 3 cm. in diameter, with a central hole about 1 cm. in diameter, was placed between the plates *f* and *d*, as shown in fig. 2. The wires to which the plate was attached made contact with the



gauze, and it was therefore raised to the same potential. The plate *f* was moved into the path of the beam of light and the rod *g* connected with the electroscope, while the rod *e* was kept earthed. The gauze was at a positive potential of 200 volts, and a leak was caused in the same way as before by the action of the light on the film of gold leaf on the plate *f*. Leaks were taken with the quartz plate in the path of the beam of light and with the beam unrestricted. When the platinum film was facing the source of light the ratio of the leaks was 0.541, this result being the mean of six readings. After an hour another set of readings was taken, which gave the value 0.553. The quartz plate was then turned round so that the platinum film was facing away from the source of light, and measurements carried out in the same way as before. The ratio deduced from the first set of measurements was 0.551, and another set of measurements carried out later gave 0.548. These results show that the same proportion of the beam of light is reflected by the quartz plate and film in the two cases. The intensity of the emerging light, it will be seen, is in both cases about 55 per cent. of that of the primary beam.

The results of the experiments may now be summed up as follows: Let us neglect the absorption of the light by the quartz plate. The amount of cathode radiation produced in the film would then be the same in the two positions of the quartz plate and film. We may then suppose that the film remained stationary, and measurements of the cathode radiation were carried out for both sides of the film. We then have that if we denote by unity the intensity of the light entering the film, the intensity of the light emerging at the other side is 0.55. And if the intensity of the cathode radiation on the side where the light enters is denoted by unity, the intensity of the radiation on the other side is 1.15. Now, if the electrons were ejected in all directions by the ultra-violet light, the cathode radiation on the emergence side, as already stated, should be smaller than that on the incidence side. The effect of the absorption of the light by the quartz plate in the actual experiments, it will be observed, is to decrease instead of increase this asymmetry. The experiments thus seem to show conclusively that the ejected electrons have a component of motion in the direction of propagation of the light.

Rubens and Ladenburg* have carried out some experiments on ultra-violet light, and obtained results which at first sight seem to indicate the existence of the above effect. These physicists did not undertake the experiments with the object of looking for the effect in question, and therefore do not draw any conclusions from their results relating to it. It will not be out of place, however, to investigate here whether some of their results have any connection with the subject.

* 'Berl. d. Deuts. Phys. Gesell.,' vol. 24, p. 749, 1907.

They passed a beam of ultra-violet light through different thicknesses of gold leaf to see whether the cathode radiation is a surface effect. Measurements of the intensity of the cathode radiation and that of the light emerging from or incident on the gold leaf were carried out for both sides of the leaf. The intensities of the incident and emergent pencils of light when one gold leaf was used were in the ratio of 1000 to 1, and the corresponding cathode radiations were in the ratio of 100 to 1. If the ratio of the intensity of the cathode radiation to that of the light incident on the leaf is denoted by unity, the ratio on the side where the light emerges will be 10. But this asymmetry does not show without further investigation that the cathode radiation is ejected in the direction of propagation of the light. The light as it passes through the gold leaf gradually decreases in intensity. The intensity of the cathode radiation at any point in the leaf will be proportional to the intensity of the light, and the intensity of the cathode radiation in the leaf thus gradually decreases as we pass from the side where the light enters to the other side. The ratio of the intensity of the cathode radiation at a point in the leaf to the intensity of the light falling on the leaf therefore decreases as we pass through the leaf in the direction of propagation of the light, while the ratio of the cathode radiation to the intensity of the light emerging from the leaf increases as we pass through the leaf in the opposite direction. Therefore, since according to Rubens and Ladenburg the cathode radiation emerging from the leaf is made up of radiation from all parts of the leaf, the ratio of the cathode radiation emerging from the leaf on the side on which the light falls to the intensity of the light should be smaller than the ratio of the intensity of the cathode radiation to that of the light emerging from the other side. To determine, then, whether this asymmetry shows that the ejected electrons move with the light requires some calculations to determine if the asymmetry is greater than it should be on the supposition that the electrons are ejected equally in all directions. These calculations would involve the coefficient of absorption of the cathode rays and that of the light, quantities whose magnitude is at present unknown. But when the cathode radiation on the side of a metal film where the light emerges is greater than that on the other side, as was the case in the writer's experiments, we have direct evidence that the cathode rays are ejected in the direction of propagation of the light. Rubens and Ladenburg's results cannot, therefore, as they stand, be said to constitute any evidence to show that the effect under discussion exists.

The result obtained in this paper is of interest in connection with the action of light on free electrons. From the nature of the results it seems reasonable to expect that a forward motion would also be given to an electron

when not associated with an atom on a wave of light passing over it. The experiments thus afford evidence in support of the theory that some of the free electrons which exist in the solar atmosphere, or in the atmosphere of any incandescent heavenly body, are driven into interstellar space by the light of the body. These streams of electrons are supposed by some physicists and astronomers to produce the aurora, and to give rise to the tail of comets.

I wish to thank Prof. Sir J. J. Thomson for his interest in these experiments.

[*April 22.*—After the foregoing paper had been written, it was suggested to the writer that the result obtained would appear more conclusive if the experiments had been carried out with the chamber exhausted to a high vacuum. Now, the ionisation of the air in the chamber by the ultra-violet light was negligible in comparison with the negative leak from the platinum film, as was shown by the complete absence of any leak when the gauze was raised to a negative potential. The only effect produced by the presence of the air is to impede the escape from the film of the negative particles which are produced by the light, so that a strong electric field had to be applied to produce a separation of the particles from the film. But the arrangement of the apparatus was such that the asymmetry in leaks observed could not in any way be due to this.

However, a set of experiments was now carried out with the chamber evacuated. The chamber was first exhausted down to about 2 cm. of mercury and the residual air absorbed by charcoal contained in a glass bulb which was placed in liquid air. The rod and tube joint was made air-tight by passing a tightly fitting rubber tube over it. The section of the aperture in the gauze through which the pencil of ultra-violet light entered the chamber was reduced in size, which had the effect of rendering the electric field more uniform at that part of the gauze. Observations were carried out with the gauze at a positive potential of 2 volts. When the film was facing the source of light it took the gold leaf of the electroscope 23.2 seconds on the average to move over five divisions of the scale, and when it was facing in the opposite direction the time was 20.2 seconds, which shows that the cathode radiation from the film is at least 14 per cent. greater in the latter case than in the former.

Another wire gauze was next placed in the chamber, parallel to the gauze with the aperture, so that the quartz plate was midway between these two gauzes. This was done in order that the electric field between gauze and

platinum film should be of the same intensity in each of the two different measurements. Joining the gauze to a positive potential of 4 volts, it was found that when the film was facing the source of light it took the leaf of the electroscope 36.5 seconds to move over 10 divisions of the scale, while it took 31.1 seconds when it was facing in the opposite direction. The negative leak from the film in the latter case is thus about 17 per cent. larger than in the former. The asymmetry in the leaks is slightly greater than that obtained before, owing to a different distribution of the electric field, the leak being not altogether independent of the intensity of the electric field even at the low vacuum obtained. In the former case the distribution of the field was such as to have a tendency to produce an asymmetry in the leaks of type opposite to the one observed.

When the gauze was raised to a negative potential practically no leak was observed. The results obtained thus support those obtained previously.]

On the Absorption of Gases by Charcoal.

By Miss I. F. HOMFRAY, D.Sc.

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The objects of the present research were: Firstly, to obtain accurate and systematic measurements, over as wide a range as possible, of the three variables in the charcoal-gas system, temperature, pressure, and volume of gas absorbed, for a number of different gases; secondly, to deduce therefrom some generalisations which should bring into line this mass of otherwise un-coordinated data; finally, to employ these relations, if justified by sufficiently wide applicability, to throw some light on the nature of the phenomena with which we are dealing.

The apparatus used was, essentially, a gas thermometer, the bulb containing 3 grammes of carefully purified cocoanut charcoal, connected with a mercury pump and gas burette. The dead space was found by calibration, and the actual volume of the gas-free charcoal by a separate series of experiments. Successive volumes of gas were admitted, and the pressures, up to 80 cm. of mercury, read at definite selected temperatures, ranging from that of boiling aniline to that of liquid air.

The volumes absorbed were calculated by difference, reduced to normal